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9.—A Naturally Etched Australite from Narembeen, Western Australia

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A large boat-shaped australite weighing a little over 100 grams from Narembeen, Western Australia, has been naturally etched to produce abundant solution grooves on all surfaces. It is one of the very few, among some 40,000 known specimens of australites, that shows a sculpture pattern with prominent straight, circular and vermicular grooves resembling the U-shaped grooves on some specimens of billitonites and the "gouttières" on some indochinites. The grooves and pits on all surfaces of the specimen are essentially due to solution-etching that was primarily initiated along more readily etchable bundles of schlieren in the tektite glass. The longer grooves followed schlieren more or less parallel with the surface of the specimen; the pits and the circular grooves enclosing islands, thus producing structures resembling "höfchen" and "tischchen" on billitonites are an expression of differential solution along bundles of schlieren more or less normal to the surface of the specimen.

Introduction

A large boat-shaped australite showing pronounced grooves due to solution-etching was found on April 16th, 1960, by Mr. A. W. Henderson on a gravelled road 22½ miles due east of Narembeen, a township located at 32° 05' S. and 118° 25' E. in the South West Division of Western Australia and situated 155 miles east of Perth, Western Australia. The evidence points to the specimen having been carted in from a gravel pit four miles further east and situated five miles east of Mt. Walker at approximately 32° 05' S. and 118° 45' E.

The road was gravelled some six months prior to the discovery of the australite. The specimen is now lodged in the geological collection (Reg. No. 8950) of the School of Mines of Western Australia, Kalgoorlie.

Size and Weight

The australite measures 64 mm in length, 37 mm in width and 30.5 mm in depth (= thickness). Its weight after thorough cleaning to remove all adventitious particles of terrestrial matter is 107.457 grams, but this is not the total weight of the solution-etched specimen as found, since a small, highly vitreous fractured face occurs at one end of the anterior surface (see dark area at top left-hand end

of Fig. B, Plate I). This fracture is of very recent origin as it shows no signs of having been etched; there is no evidence to show that fracturing was due to skilled aboriginal flaking and occasional "bruise-marks" on the anterior surface near the fracture suggest that the specimen was struck with a hammer.

The specific gravity as determined on a Mettler K-type balance in distilled water ($T_{H_2O} = 12.8^\circ \text{C.}$) is 2.431. This is above the average for australites generally (cf. Baker and Forster 1943, p. 403), but lower than the average for seven boat-shaped australites from the Coolgardie district of Western Australia (Baker and Forster 1943, p. 385), and higher than most specific gravity values for australites from eastern Australia (Baker and Forster 1943, Table 3).

Only twelve other australites are known to science that weigh over 100 grams, and one-third of these are boat-shaped forms.

Curvature of Surfaces

Approximate values for the radii of curvature of the posterior and anterior surfaces as measured along the long axis of the specimen are:

$$R_B = 57.9 \text{ mm,}$$

$$R_F = 46.2 \text{ mm,}$$

where R_B = radius of curvature of the posterior (back) surface and R_F = radius of curvature of the anterior (front) surface, nomenclature of the surfaces being according to the flight orientation through the atmosphere. The anterior surface thus shows a rather steeper arc of curvature compared with the posterior surface. The surface curvatures along this direction are not quite coincident with the arcs of curvature of constructed circles having the above radii, being a little flatter in the polar regions and somewhat steeper near the equatorial edge.

Across the width or shorter diameter of the specimen, the arcs of curvature of both the posterior and the anterior surfaces more closely fit those of constructed circles with the same radius of curvature, and both R_B and $R_F = 21.0 \text{ mm.}$ A cross section of the specimen, however, is not circular (cf. end-on view, Fig. D, Plate I) because the centres of the two arcs of curvature

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are not coincidental, being 11.1 mm apart on the same axis (the polar axis as projected in the line of flight). The constructed circles are coaxial and the centres collinear. Reconstruction of the form to its complete state prior to modification by aerodynamic frictional heating during high speed flight through the earth's atmosphere, reveals that a depth of 11.1 mm was removed by ablation of tektite glass from the front polar regions (i.e. at the stagnation point —cf. Baker 1961b) on the anterior surface.

Refractive Index and Silica Content

The refractive index of the tektite glass constituting this australite from Narembreen, as determined by the Immersion Method utilising monochromatic (Na) light is:—

$n_{Na} = 1.508$ to 1.510 for schlieren of slightly different chemical composition. From the relationship $k = n - 1/d$, the specific refractivity (k) of the glass is 0.2094 . (n = refractive index; d = specific gravity).

Tektite glass with a specific gravity of 2.431 and a refractive index of 1.509 (average of measurements), contains approximately 71 per cent. SiO_2 according to the Silica-Refractive Index and Silica-Specific Gravity graphs for tektites generally (cf. Barnes 1940; Baker 1959).

Nature of Sculpture

The australite from near Narembreen shows marked evidence of having been subjected to relatively strong solution-etching (Plate I) while buried in thin superficial terrestrial materials (sandy to gravelly soils). This has produced etch pits and both straight (linear and forked) and meandrine shallow grooves, the deeper of which sometimes cut across the trends of shorter, shallower grooves. The greatest width of the grooves is 1 mm; they are 0.5 mm to 1 mm deep and open U-shaped in cross section (cf. top right, Fig. C, Plate I).

The specimen is one of the very few australites on which the corrosion sculpture constituted largely of vermiform grooves and etch pits is so marked as to strongly resemble similarly solution-etched specimens of certain billitonites and indochinites. The sculptural detail is shown in Plate I, figures A to E, and this compares with the sculpture of billitonites (cf. Baker 1959, Plate I, Figs. A to D), although many grooves on the billitonites are often somewhat deeper than those on this australite.

The aerodynamically stable orientation of australites during unidirectional, non-rotational transit at high speeds through the earth's atmosphere is such that the anterior surface remains projected forward in the line of flight throughout the ablative phase. On this basis, the fact that the grooves are as equally well-developed on both anterior and posterior surfaces is adequate confirmation of the postulate

that such grooves are not elements (i.e. piézo-glyphs) of a sculpture pattern produced by aerodynamic friction and ablation during earthward flight, for the posterior surface was never exposed to the action of aerodynamic friction in the sense in which the anterior surface was exposed.

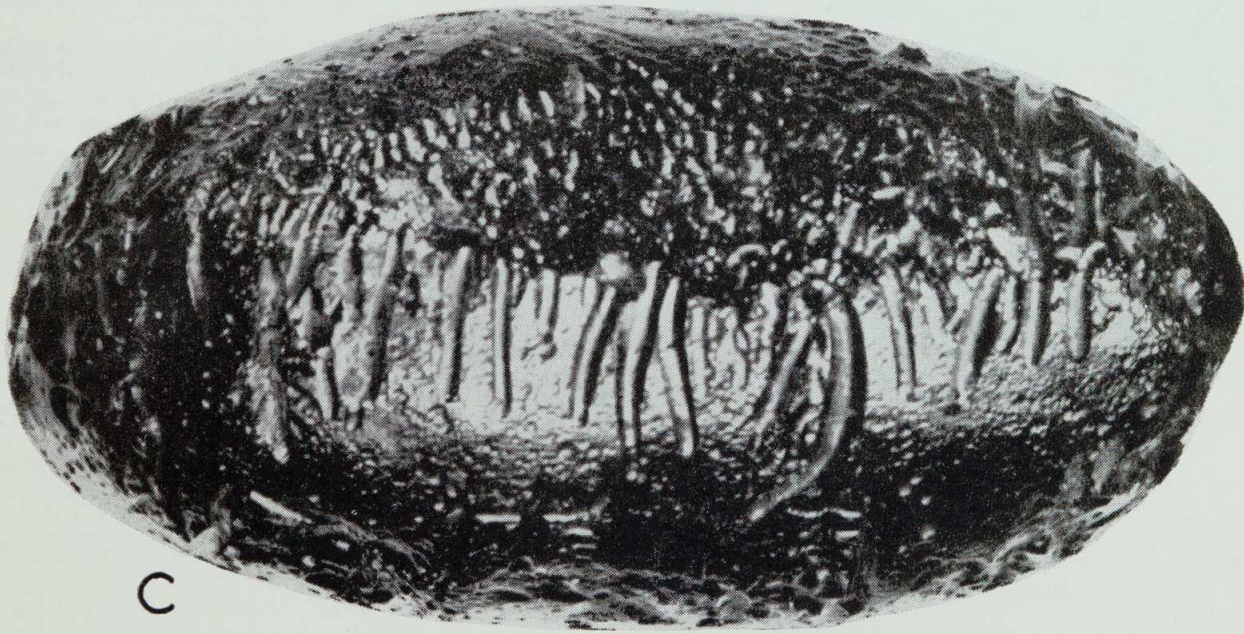
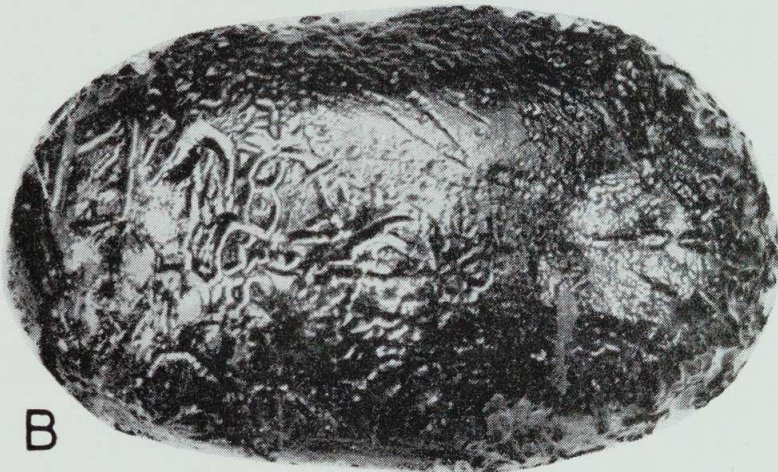
Furthermore, the results of etching experiments on worn australites (Baker 1961) substantiate the theory that such grooves or channels are a result of solution-etching by sub-aerial terrestrial agents that came into operation after the australite had landed upon the earth's surface.

Many of the solution grooves follow the trends of certain flow-line directions that consist fundamentally of rather more etchable schlieren, hence the surface pattern of the chemically corroded form is essentially an external expression of a relatively complex streaky internal structure. The long and short grooves, whether straight or meandrine, occupy the sites of bundles of schlieren trending parallel with the surface of the tektite. Circular grooves enclosing small islands of tektite glass and forming structures resembling the better developed "höfchen" and "tischchen" structures on billitonites are formed in regions where the bundles of schlieren trend more or less normal to the tektite surface; the more readily etchable groups are dissolved to leave roughly circular grooves enveloping less readily attacked "small tables" (cf. Plate I, Fig. B, left-hand end). Finer flow-lines ("fiederung") trending across some of the vermiform and circular grooves in places result in a segmented appearance detectable under higher magnifications (e.g. with a $10\times$ hand-lens). The smaller, round, more regular pits on the surface of the tektite are evidently "out-crops" of internal small bubbles exposed by removal of the outer zones of the glass by chemical corrosion.

With more pronounced solution-etching along certain directions than along others, some of the deeper grooves so truncate shallower channels that they end abruptly at the walls of the deeper grooves and remain as small U-shaped "hanging valleys". Differential solution of this nature is probably a reflection of more constant supplies of etchant (soil solutions) that became directionalised along certain trends determined initially by compositional differences from schliere to schliere. Once the process was initiated, there would be a tendency for etchants to lodge for somewhat longer periods in small depressions on the specimen. The sub-arid nature of the area where the specimen was discovered suggests that etchants would only be periodically available throughout the year, but supplies could have been rather variable during the past 5,000 years that the specimen has lain in soils on the earth's surface (cf. Baker 1961a).

PLATE I.

Boat-shaped australite from gravelled road $22\frac{1}{2}$ miles due east of Narembreen, Western Australia. (Reg. no. 8950, Geological Collection, School of Mines of Western Australia, Kalgoorlie). Figures A to E show solution etch grooves on all surfaces, some extending from the posterior to the anterior surfaces and cutting across the rim (Figs. D and E), others terminating at the rim (Fig. C). A = anterior surface ($\times 1.16$); B = posterior surface, slightly chipped at left-hand end ($\times 1.20$); C = side view (reverse side to Fig. E), with posterior surface at top ($\times 1.92$); D = end-on view, with posterior surface at top ($\times 1.05$); E = side view (reverse to Fig. C), with posterior surface at top ($\times 1.20$). (Photographs by K. L. Williams.)



Comparison with Other Large, Boat-shaped Australites

Compared with other large, but not as heavy boat-shaped australites such as from Kaniva (95.85 grams), Ellerslie (47.75 grams) and Port Campbell (29.48 grams) in western Victoria (Baker 1940, Plate XII, Figs. 1, 5 and 9), the specimen from Narembeen reveals much more prominent and more abundant, deeper solution grooves. Furthermore, it does not possess a naturally flaked equatorial zone like these specimens, and thus resembles a boat-shaped specimen (88.45 grams) from Corop, Victoria (Baker 1940, Plate XXII, Fig. 2) and another (141.63 grams) from Port Campbell, Victoria (National Museum of Victoria, Reg. No. 11402), except that the rim separating the anterior and posterior surfaces is not nearly as well-preserved on the Narembeen specimen.

The absence of a flaked equatorial zone (cf. Baker 1940, p. 488) which is normally a common feature of the larger australites such as round cores, oval cores and boat-shaped cores, raises the question (a) whether a flaked equatorial zone was present when the Narembeen boat-shaped australite landed, and whether this flaked zone was subsequently destroyed by advanced degrees of solution-etching especially in the equatorial regions, or (b) whether a flaked equatorial zone did not develop during atmospheric flight for the reason that the initial angle of entry might have been too high for aerodynamic friction and heating to cause fusion stripping in equatorial regions. The appearance of the form in side and end-on aspects is such as to lend some support to (b). Furthermore, Fenner (1935, p. 130) has figured a few specimens of australites under the term "indicators" which show flaked equatorial zones developing largely as a consequence of subaerial erosion, but these

are usually much smaller specimens than the example studied herein.

Whether or not some flaked equatorial zones are due to fusion stripping during atmospheric flight and others to subsequent corrosion and flaking from the action of subaerial agencies operating after the australites landed upon the earth's surface, it is apparent that both processes can have been responsible in reducing, or in combining to reduce, the bulk of the primary form of the boat-shaped australite from Narembeen by at least one-third, and probably more.

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